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Strip Sampling with Airborne Video for Assessment of Blowdown Caused by Straight Line Winds

ABSTRACT

Strip sampling with an S-VHS airborne video system, equipped with a GPS interface, was used to assess forest damage caused by a severe windstorm on the Superior National Forest and intermingled state and private lands in northern Minnesota. This technique was tested as a method of rapid assessment of forest damage from storm events. A target site of 559,442 acres, the central portion of an area damaged by a storm that occurred on 4 July 1999, was selected for the evaluation. Thirty north-south flight lines were established randomly over the target site and flown with an altitude-lens focal length combination designed to produce a 0.25-mile wide strip of video imagery.

The resulting video imagery was analyzed using visual interpretation, and damage was classified into three classes: light, moderate, and heavy. Two methods of data capture were used and compared with an aerial sketchmap survey conducted immediately after the storm occurred. The first method involved classification of individual frames of video imagery along each flight line. The number of scenes in each class was multiplied by the area covered per frame to compute the area of each damage class per flight line. The second data capture method involved analysis of the entire strip and recording times over each damage class. Times were converted to area using a simple ratio conversion. In addition, a map was produced from the imagery by plotting locations of classified damage onto the flight lines and interpolating between flight lines. Both methods produced area estimates for each damage class within 95 percent confidence limits.

The statistical data and damage map produced by the video imagery were comparable to an aerial sketchmap survey conducted over the affected area. This leads to the conclusion that strip sampling with airborne video imagery is a viable alternative to aerial sketchmapping for rapid acquisition of data on the location and severity of forest damage caused by catastrophic climatic events and, possibly, insect defoliation. Airborne video has the inherent advantage of providing a permanent record of damage that can be re-examined should questions arise about the location or intensity of damage in affected areas.

Cover photo: William Ciesla

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by

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METHODS

Overall Approach

The overall approach to data acquisition using the S-VHS camera is based on the principle of strip cruising, or strip sampling, using procedures developed a number of years ago for estimating forest damage using an operations recorder (Heller and others 1952, Ketcham 1964). Sample strips of video imagery are acquired over the target area. The length of each sample strip and the swath width of the imagery or the area of individual frames selected for classification are used to determine the sample area. The video imagery is then viewed on a monitor in the office, and individual frames or line segments are classified according to a specified set of damage strata. The area in each damage class is determined for the sample strip. The mean area of each damage class for all flight lines, standard deviation, and standard error are computed and expanded to provide area estimates of damage.

The Target Site

A portion of the Superior National Forest and intermingled state and private lands in northern Minnesota, which suffered extensive blowdown caused by straight-line winds in excess of 90 mph on 4 July 1999, was used as the target site for this evaluation. The overall area was estimated at 559,442 acres and consisted of a block of 35 townships (T62–66N, R4–10W, fourth principal meridian) east of Ely, MN. The southern boundary of the target area was north latitude 47°48'; the northern boundary was the U.S.-Canadian border (Fig. 1).

Most of the target site lies within the Boundary Waters Canoe Wilderness Area (BWCWA), a designated wilderness, and consists of more or less continuous forest cover interspersed with numerous lakes and nonforested sphagnum bogs. The forest is a classic boreal type and consists of a mosaic of both broadleaf species (quaking aspen—*Populus tremuloides*, paper birch—*Betula papyrifera*, black ash—*Fraxinus nigra*) and conifers (white spruce—*Picea glauca*, black spruce—*P. mariana*, tamarack—*Larix laricina*, northern white cedar—*Thuja occidentalis*, jack pine—*Pinus banksiana*, red pine—*P. resinosa*, and eastern white pine—*P. strobus*).

Geologically, the area is a part of the glaciated Canadian Shield, characterized by level to gently rolling terrain and extensive wetlands. Mean terrain elevation of the target site is about 1,500 feet above mean sea level.

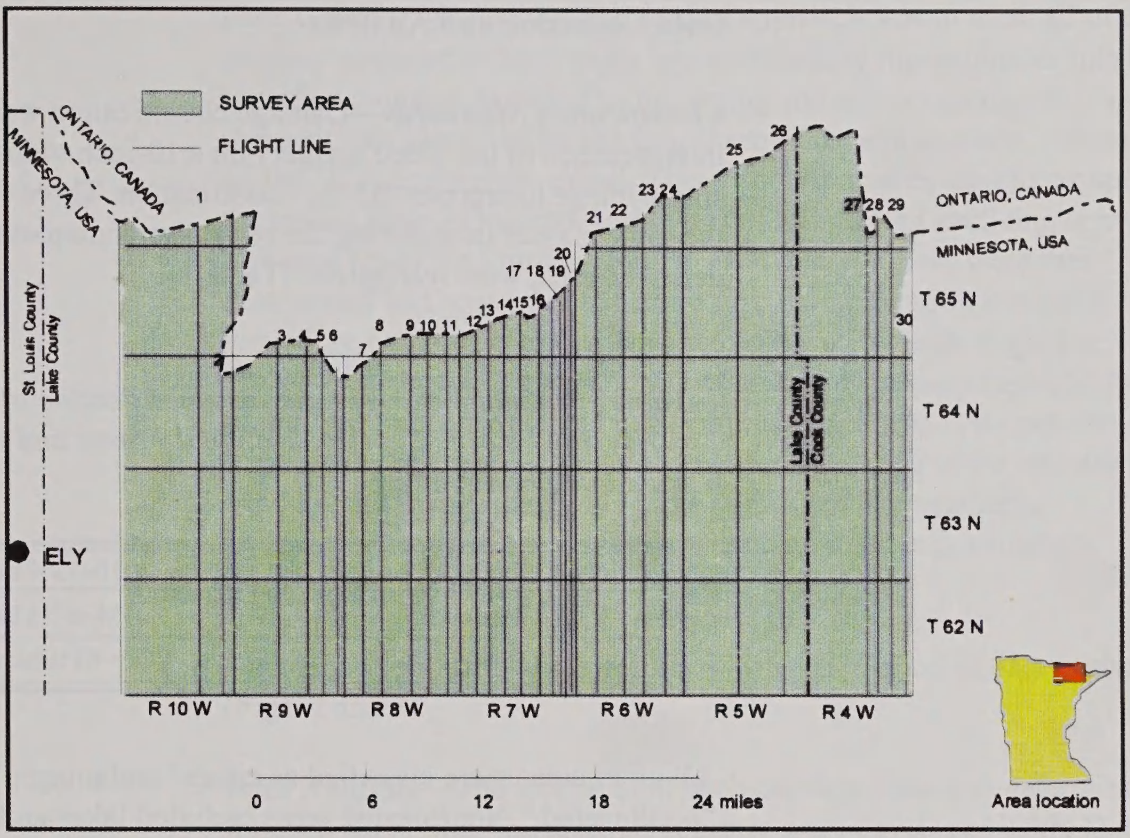

Figure 1. Area included in the target site for evaluation of airborne video imagery to assess forest damage on the Superior National Forest and intermingled state and private lands in Minnesota, August 1999

Image Aquisition

Thirty north-south flight lines, each with a video image swath width of 0.25 miles, were randomly selected from a pool of 166 possible 0.25-mile wide flight lines over the survey area. Flight strips were 16.40 to 29.50 miles long (Fig. 1). Flight lines were drawn on a ½ inch = 1 mile scale forest map, and the longitude of each flight line was determined and recorded to facilitate use of GPS for navigation during image acquisition. The imagery was acquired using a USDA Forest Service King Air aircraft (N128Z) managed by FHTET, which was in the area for a related aerial photo acquisition mission. Imagery was flown from a flying height of approximately 4,000 feet above mean sea level and 2,500 feet above ground level. The camera lens was set at a focal length of 16.5 mm to provide an image swath width slightly in excess of 0.25 miles. Aircraft ground speed averaged 180 mph.

Approximately half of the imagery (flight lines 1–6 and 21–30) was acquired on 5 August 1999. The remainder was acquired on 13 August 1999. Approximately 6 hours of flying time were required to complete the mission.

Data Collection and Analysis

Classification Standards—Damage classification was made by visual interpretation of the video imagery on a 10-inch video monitor. A single image interpreter did the classification. Three damage classes, the same classes used during the aerial sketchmap over the storm damaged area, were recognized (Table 1).

Table 1. Damage classes used for classification of storm damage 4 July 1999 storm, Superior National Forest and intermingled state and private lands

Light	10–33% blowdown
Moderate	34–67% blowdown
Heavy	$\geq$ 68% blowdown

All other areas were classified as either "undamaged" or "nonforested." Nonforested areas included lakes and treeless sphagnum bogs.

Data Capture—Two methods of data capture were used and compared.

Data Capture Method 1—The first data capture method involved classifying individual video frames at regular intervals along each flight line. The interval between images was set to include as much of the flight line as possible. This was done by dividing the total area, in acres, of each flight strip by the area of an individual video frame (30 acres) to determine the number of video frames to be sampled per flight line. The interval, in seconds, between video frames was determined by dividing the flight time over each line, in seconds, by the number of video frames per flight line. To avoid sampling the same area of land more than once, the calculated interval between video frames was rounded up to the nearest whole second. This resulted in sampling slightly less land area than the total area of the thirty 0.25-mile wide flight lines (95,850 acres instead of 101,296 acres for a sampling fraction of 17.1 vs. 18.1 percent). For this survey, the interval between frames varied from 3 to 5 seconds per flight line (Table 2). If more than 50 percent of the land area fell into a specified damage class, the entire frame was placed into that class. This method allowed for easy separation of undamaged forested areas and nonforested areas.

Data Capture Method 2—The second approach was to view all of the imagery acquired of each flight line and classify line segments into the specified damage classes. The beginning and end point of each line segment was identified by the time, in minutes and seconds, indicated on the VCR and was recorded. This information was used to compute the lapsed time, in minutes and tenths of minutes, of each line segment. The total times for line segments in each damage class were then determined and converted to acres using a simple ratio estimating procedure based on the total land area covered by each flight line (Table 2). This approach made use of all of the imagery captured for each flight line, and resulted in a sampling fraction of 18.1 percent. Because the many small lakes and nonforested bogs in the test site would result in an excessively large number of line segments, undamaged areas, lakes, and bogs were combined into a single "undamaged" class.

Data recording forms were designed for each method of data capture (Figs. 2 and 3).

Data Analysis—The total area of each damage class was determined for each flight line, and analysis routines were developed using Quattro Pro spreadsheet software to compute the mean, standard deviation, and standard error for each damage class. These were expanded for the entire 559,442-acre target area, and 95 percent confidence limits were computed. Statistical procedures used were according to Freese (1967).

Damage Mapping—A map showing general location of damage was produced by transferring the areas of damage along each flight line to the ½ inch = 1 mile scale forest map using the GPS data recorded for damaged areas. Lines were then drawn between the flight lines to delineate changes in damage.

Comparison with Reference Data

The statistical data and map produced from analysis of the airborne video imagery were compared with an aerial sketchmap survey conducted over the area shortly after the storm occurred. This survey was flown using a USDA Forest Service DeHaviland Beaver aircraft. Entire sections (about 640 acres) were classified as having light, moderate, or heavy damage. Mapping was done on 1:100,000 scale Landsat Thematic Mapper (TM) band 3, 4, and 5 composite maps, which simulate a color infrared scene, overlaid with cultural,

hydrological, and township and range data themes from USGS 1:100,000 scale topographic maps. These maps are produced by the Minnesota Department of Natural Resources.

Table 2. Flight parameters for video survey of the 4 July 1999 storm event, Superior National Forest, MN

Flight line	**Longitude** (degrees, minutes, seconds)	**Length** (miles)	**Total area** (acres) (swath width = 0.25mi)	**Number of 30-acre sample points** *Data collection method 1*	**Interval between sample points** (seconds) *Data collection method 1*
1	91 36 00	20.30	3,248	108	3
2	91 33 00	16.40	2,624	78	4
3	91 30 30	18.00	2,880	89	4
4	91 27 30	18.00	2,880	96	3
5	91 26 30	16.90	2,704	84	4
6	91 25 30	16.90	2,704	89	3
7	91 24 00	16.70	2,672	88	4
8	91 23 15	16.80	2,688	84	4
9	91 19 00	18.00	2,880	84	5
10	91 17 30	18.50	2,960	88	4
11	91 17 00	18.20	2,912	97	4
12	91 16 00	18.60	2,976	92	4
13	91 14 30	18.50	2,960	99	4
14	91 13 45	19.20	3,072	102	3
15	91 13 15	19.00	3,040	80	5
16	91 12 45	20.60	3,296	90	5
17	91 12 30	20.40	3,264	102	4
18	91 12 20	21.20	3,392	113	3
19	91 10 30	21.80	3,488	116	3
20	91 10 00	22.20	3,552	106	4
21	91 08 00	22.80	3,648	121	3
22	91 06 45	24.80	3,968	137	3
23	91 05 30	25.60	4,096	127	3
24	91 03 30	29.00	4,640	136	3
25	90 57 00	28.20	4,512	143	3
26	90 54 30	29.50	4,720	157	3
27	90 49 00	26.40	4,224	122	3
28	90 48 00	25.40	4,064	134	3
29	90 47 30	23.60	3,776	121	3
30	90 46 45	21.60	3,456	112	4
TOTAL			101,296	3,195	

INDIVIDUAL FLIGHT LINE DATA SUMMARY
(Data Capture Method 1)

Survey date: *05 Aug 99* State: *MN* Unit: *BWCWA*

Swath width: *0.25 miles* Flight line: *8* Flight line GPS: *91°23'15"* Flight line length: *16.8 miles*

Plot area (acres): *30* GPS starting point: *48°01'00"* GPS ending point: *48°07'45.3"*

Plot number	GPS point	Nonforested	Undamaged	Light	Moderate	Heavy
1	*48°01'50"*	*X*				
2	*48°02'00"*	*X*				
3	*48°02'20"*		*X*			
4	*48°02'40"*	*X*				
5	*48°02'59"*		*X*			
6	*48°03'21"*		*X*			
7	*48°03'40"*		*X*			
8	*48°04'01"*	*X*				
9	*48°04'22"*	*X*				
10	*48°04'41"*	*X*				
11	*48°04'58"*		*X*			
12	*48°05'19"*		*X*			
13	*48°05'39"*			*X*		
14	*48°05'58"*			*X*		
15	*48°06'18"*				*X*	
16	*48°06'37"*				*X*	
17	*48°06'56"*					*X*
18	(Continued on next page)					
Stratum totals (number of plots)		*6*	*6*	*2*	*2*	*1*
Stratum totals (acres)						

Figure 2. First page of sample data recording form for classifying damage on individual video frames (data capture method 1)

INDIVIDUAL FLIGHT LINE DATA SUMMARY
(Data Capture Method 2)

Survey date: *13 Aug 99* State: *MN* Unit: *BWCWA*

Swath width: *0.25 Miles* Flight line: *14 N-S* Flight line length (miles): *19.20*

Flight line area (acres): *3,072* GPS starting point: *48°07'48.7"* GPS ending point: *47°47'59.1"*

Line segment	Start	Stop	Nonforested or undamaged	Light	Moderate	Heavy	Total
A-B	*34:47*	*35:54*	*0.12*				
B-C	*34:54*	*35:03*			*0.15*		
D-E	*35:03*	*37:03*				*2.00*	
E-F	*37:03*	*37:45*	*0.70*				
F-G	*37:45*	*38:01*		*0.27*			
G-H	*38:01*	*40:34*	*2.55*				
H-I							
I-J							
J-K							
K-L							
L-M							
M-N							
N-O							
O-P							
P-Q							
Stratum totals (minutes)			*3.37*	*0.27*	*0.15*	*2.00*	*5.79*
Stratum totals (%)			*0.5820*	*0.0466*	*0.0259*	*0.3454*	*1.00*
Stratum totals (acres)			*1,788.02*	*143.25*	*79.59*	*1,061.14*	*3,072.00*

Figure 3. Sample data form for classifying line segments of video imagery (data capture method 2)

RESULTS

Image Quality

Image quality was excellent even though weather conditions varied from partly cloudy to nearly 100 percent cloud cover with intermittent rain during the days the imagery was acquired. Damage caused by the 4 July 1999 storm was clearly visible on the video imagery and could easily be classified using a 10-inch video monitor. Analysis of the imagery showed that the most severe damage occurred in the broadleaf (aspen-birch) forests. In areas of heavy damage, complete blowdown of broadleaf stands interspersed with small patches of relatively undamaged conifers (presumably spruce and fir) was a common occurrence (Fig. 4).

The GPS receiver did not receive sufficient signals to record latitude and longitude on all of flight lines 1–6 and 30, and a portion of line 7. Where GPS data were not available, the lapsed time shown on the VCR clock was used to identify the individual video frames selected for classification during data capture method 1, and as many of the points as possible were pinpointed on the forest map to facilitate location of the sample points for subsequent damage mapping.

Photo: Barry Russell

Figure 4. Airborne S-VHS image of heavy storm damage in broadleaf forests interspersed with relatively undamaged conifer stands, Superior National Forest, MN

Data Capture

Both data capture techniques—classification of individual frames at specified intervals along each flight line and classification of the entire flight line—worked well. The individual video frame classification (data capture method 1) required about 11 hours of image analysis time, while the classification of entire flight lines (data capture method 2) required 5.5 hours. Classification of individual frames (data capture method 1) provided for separation of undamaged forest and nonforested areas (lakes and bogs), which was not practical during the classification of entire flight lines because of the large number of lakes in the target area. A drawback of data capture method 2 was that it was sometimes difficult to detect transitions between no damage and light damage, and between light damage and moderate damage.

Damage Estimates

Estimates of damage produced by the two methods of data capture are comparable (Tables 3 and 4); however, the estimates of damaged forest provided by data capture method 2 are somewhat higher.

Table 3. Estimates of forest damage caused by the 4 July 1999 storm, video demonstration site, Superior National Forest, MN, based on classification of individual scenes at specified intervals along flight lines[1] (data capture method 1)

Damage class	Area affected (acres)	95% confidence limits	Percent of area
Nonforested[2]	90,852.54	± 12,562.67	16.24
Undamaged	287,583.24	± 18,640.42	51.41
Light damage (10–33%)	45,950.42	± 15,530.84	8.21
Moderate damage (34–67%)	34,768.57	± 11,294.18	6.21
Heavy damage (≥ 68%)	100,287.23	± 15,292.50	17.93
Total area	559,442.00	—	100.00

[1]Based on a sampling fraction of 17.2%
[2]Includes lakes and sphagnum bogs

Table 4. Estimates of forest damage caused by the 4 July 1999 storm, video demonstration site, Superior National Forest, MN, based on classification of entire flight line[1] (data capture method 2)

Damage class	Area affected (acres)	95% confidence limits	Percent of area
Undamaged[2]	322,321.97	± 21,546.16	57.61
Light damage (10–33%)	48,153.47	± 18,975.49	8.61
Moderate damage (34–67%)	63,531.11	± 20,680.84	11.36
Heavy damage (≥ 68%)	125,435.74	± 22,028.97	22.42
Total area	559,442.29	—	100.00

[1]Based on a sampling fraction of 18.11%
[2]Includes lakes and sphagnum bogs

Comparison with Reference Data

Both the statistical data and the map produced from analysis of video imagery compare favorably with the data derived from aerial sketchmapping (Table 5). Aerial sketchmapping produced the highest estimates of light damage, video data capture method 1 produced the most conservative estimates of damage, and video data capture method 2 produced the highest overall estimates of damage (Fig. 5). The maps produced from both sketchmapping and airborne video show a band of heavy damage across the northern portion of the target area (Figs. 6 and 7). This band is relatively narrow in the western portion of the target area and wider in the eastern portion. Both maps show scattered damage in the southern half of the target area. The map produced from analysis of video imagery shows significantly less scattered damage, especially in the southeastern portion. This is attributed to large gaps in area covered between flight lines 24 and 25, and flight lines 26 and 27 due to the complete random selection of the flight lines.

Table 5. Estimates of forest damage caused by the 4 July 1999 storm, over the video demonstration site, made from aerial sketchmap surveys, Superior National Forest, MN

Damage class	Area affected (acres)	Percent of area
Undamaged[1]	320,562	57.3
Light damage (10–33%)	70,240	12.6
Moderate damage (34–67%)	59,680	10.7
Heavy damage (≥ 68%)	108,960	19.4
Total area	559,442	100.0

[1]Includes lakes and sphagnum bogs

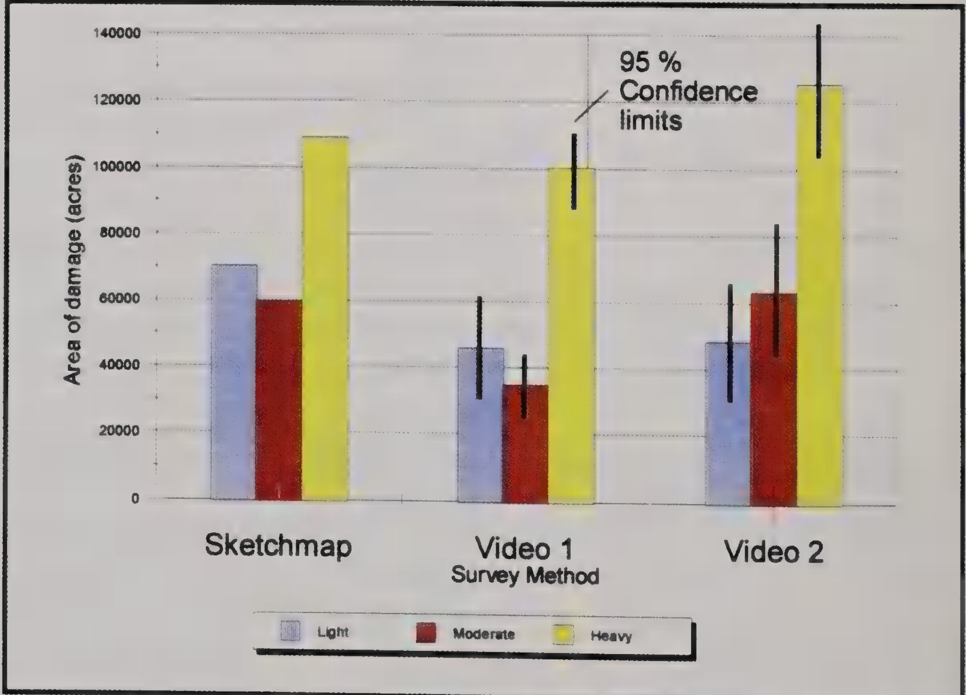

Figure 5. Comparison of estimates of forest damage caused by the 4 July 1999 storm derived from aerial sketchmapping and two methods of analysis of airborne video data, Superior National Forest, MN

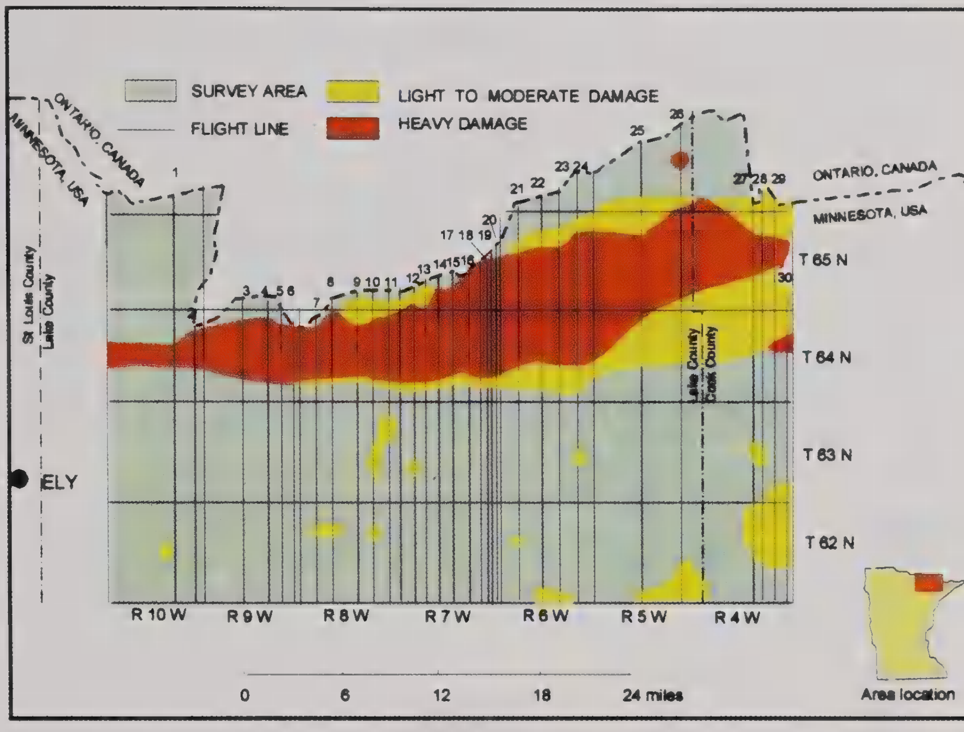

Figure 6. Map of forest damage caused by the 4 July 1999 storm derived from analysis of airborne video imagery, Superior National Forest, MN, using data from both data capture methods 1 and 2

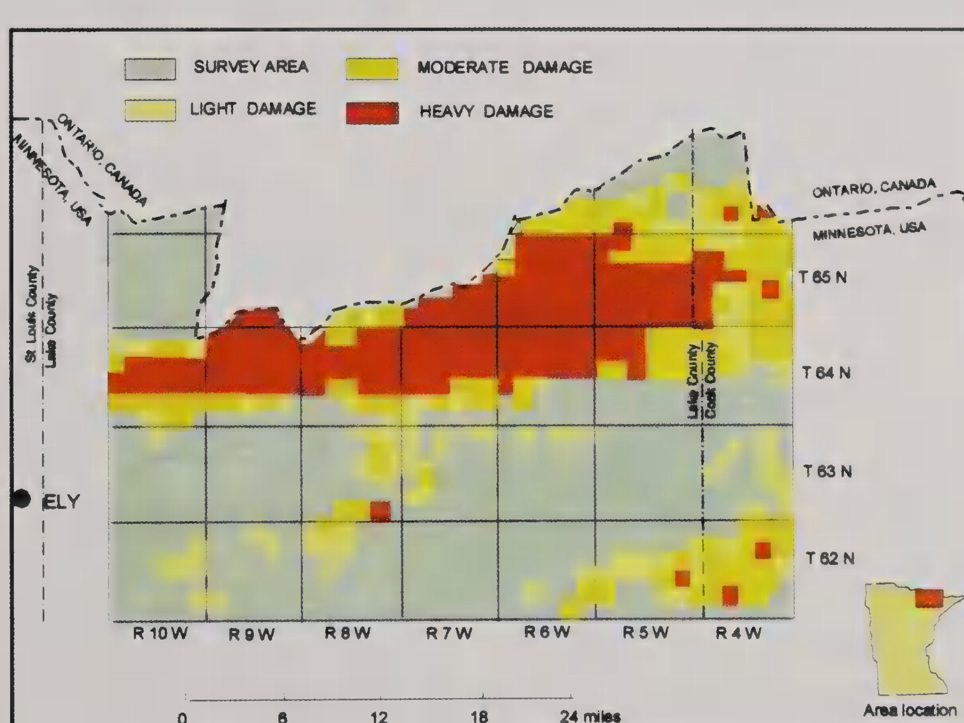

Figure 7. Map of forest damage caused by the 4 July 1999 storm derived from aerial sketchmapping, Superior National Forest, MN

Possible Sources of Error

Sources of measurement error during data capture included the following.

1. Variations in airspeed of the aircraft could not be accounted for when determining the interval between individual video frames classified during data capture method 1.
2. Changes in aircraft flying height and/or terrain elevation caused variations in the width of the sample strip and the area covered by individual frames.

Due to the relative low resolution of the video imagery, areas of recent timber harvest outside of the wilderness boundary were sometimes difficult to separate from storm damaged areas. This resulted in a possible commission error during the classification process.

A possible source of statistical error was the use of flight lines of unequal length due to the irregular northern boundary of the survey area. The data analysis method gives equal weight to each flight line, regardless of length and sample area. This could result in error in the computation of sampling errors and confidence limits. Ideally, flight lines of equal length should be used in strip sampling surveys.

CONCLUSIONS AND RECOMMENDATIONS

Strip sampling of forest areas with airborne video, using visual analysis of the resulting imagery, is a viable alternative to aerial sketchmapping for assessing forest damage caused by catastrophic climatic events. While no direct cost comparisons were made between the airborne video survey and aerial sketchmapping in this demonstration, it has been shown that when using equivalent aircraft, costs between the two data acquisition methods are comparable (Myhre and Silvey 1992). Airborne video methodology offers an advantage over aerial sketchmapping in that it provides a permanent record of the damage that can be re-examined should questions arise about the validity of the image classification. Moreover, video imagery can be acquired during the same range of weather conditions as aerial sketchmapping. Aerial photos, another remote sensing tool that provides a permanent record of the damage, can only be acquired during cloud free or nearly cloud free days. The strip sampling method used in conjunction with the image acquisition provides estimates of damage within user specified confidence limits, a measure of the reliability of the data. Maps showing the general location of damage can be produced from the data.

The survey methods described in this paper can be used for rapid assessment of areas of widespread damage caused by storms and, possibly, forest defoliation such as that caused by gypsy moth (*Lymantria dispar*), forest tent caterpillar (*Malacosoma disstria*), or spruce budworm (*Choristoneura fumiferana*). The methodology, as developed to date, is usable only in areas of relatively level terrain because abrupt changes in elevation will result in changes in flight line swath width. Data capture method 1, in which individual frames at specified time intervals are classified, could be adapted to mountainous terrain by computing the area covered by each frame selected for classification based on ground elevation and flying height.

This evaluation identified several opportunities to strengthen the methodology, including the following.

1. Record both GPS points and lapsed time on the data recording forms.
2. Use a "systematic unaligned" method of flight line location. This involves dividing the length of the survey area by the desired number of flight lines to produce equal sized blocks within which to select flight lines. Place one flight line randomly within each block. This should avoid large gaps between flight lines and reduce the risk of missing relatively small areas of damage that should be mapped.

3. Evaluate a 0.50-mile swath width for ability to resolve storm damage. The wider swath width might provide more landmarks for tracking should the GPS fail to receive sufficient signals and will increase the sampling fraction.
4. Wherever possible, use flight lines of equal length.

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